KLINOSTATS AND CENTRIFUGES FOR PHYSIOLOGICAL RESEARCH.[1]

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(WITH THREE FIGURES)

SOME years ago, when the author had to make use of the klinostat for extensive experimentation, the work went so slowly with one machine that means were sought to secure the operation of several klinostats at the same time without incurring the expense incident to the purchase of a number of the costly machines in common use. After some attempts to construct apparatus on too light and too cheap a scale, the apparatus here described was designed and manufactured with the cooperation of Mr. RALPH MILLER, at that time university mechanician. It has been used extensively for seven years, and has answered every demand made upon it. It is herewith described partly in response to several inquiries by men in other universities, and partly with the hope that it will be welcomed as offering a means for various kinds of research now practically impossible with the spring machines.

This apparatus can be provided with a horizontal and a vertical klinostat to run at the same time, the whole costing less than a Pfeffer machine; and the number of turn-tables can be increased almost indefinitely. Moreover, it will carry a much greater load than the spring klinostats.

I. CENTRIFUGES.

For both the centrifuges and klinostats the same motive power is used—an electric or a water motor. I have found it convenient to have both kinds of motors; for while the electric motor runs more evenly and with less noise, the current is more liable to interruption from one cause or another. Should one have the advantage of a constant head of water, secured by a tank with constant water level, as suggested by ARTHUR,[2] a water motor alone would suffice.

[1] Contribution 83 from the botanical laboratory of the University of Michigan.

[2] ARTHUR, Water power for botanical apparatus. Proc. Indiana Acad. Sci. 1897: 156.

By a series of pulleys on shafts, as shown in *fig. 1*, any desired speed of revolution can be secured. In the figure two centrifuges are shown for revolution on a horizontal axis. The centrifuge nearer the motor shows a large chamber fastened to the revolving plate, as already described from this laboratory by REED,[3] while the centrifuge at the right carries a plate of ordinary size—about 15^{cm} in diameter.

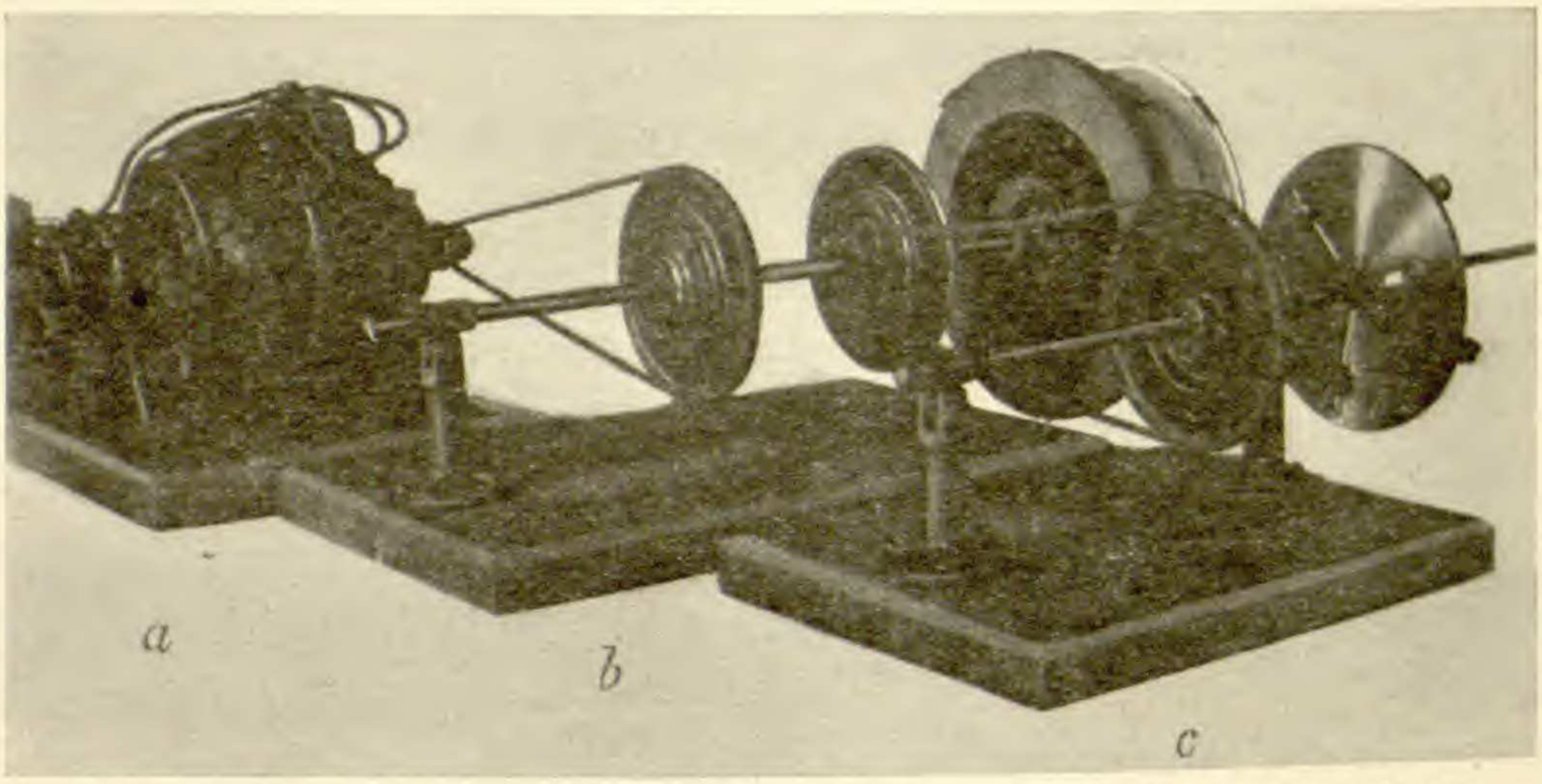

FIG. 1.—Electric motor (*a*) and two horizontal centrifuges (*b* and *c*).

II. THE KLINOSTATS.

The centrifuges of *fig. 1* are immediately turned into klinostats by the interposition of a worm reducing gear between the motor and the first shaft pulley. *Fig. 2* shows the apparatus set up for klinostat revolution; but in this figure, instead of the simple shafting with plate attached, as in *fig. 1*, we have a special form of klinostat shown, a form capable of revolution about either a vertical (*a*), a horizontal axis (*b*), or any oblique axis.

III. DESCRIPTIVE DETAILS.

The chief excellencies of this apparatus are found in what may be termed its unit construction, enabling an interchange of parts and an indefinite increase of turn-tables. The shafts are all the same diameter, the pulleys are interchangeable, and the shaft supports are all the same size.

[3] REED, A damp-chamber for use on the klinostat. Jour. Appl. Micros. 4:1499. 1901.

The motors.—Instead of temporizing with cheap motors, it is better to purchase those of known efficiency at the outset. A one-fourth horse-power will do the work well. A constant water pressure or a constant electric current will demand only one motor. Neither of these sources of power being always constant at this university, I had to purchase both kinds of motors. The water motor is a Pelton $\frac{1}{4}$ HP with a water head of about 10^{m}. The electric is a Sprague-Lundell pattern, $\frac{1}{4}$ HP. Both motors have a speed of 1,600 revolutions per minute.

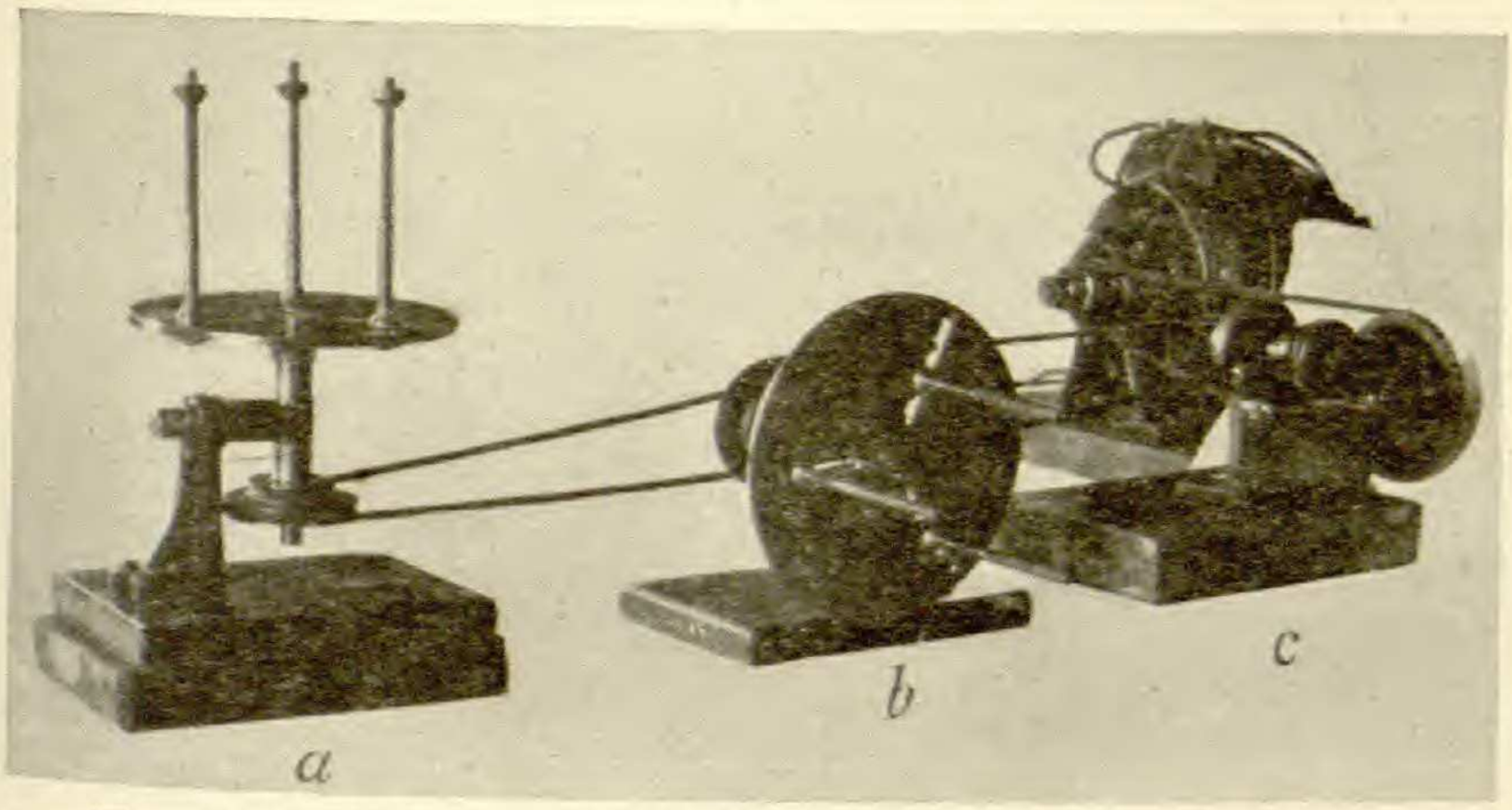

FIG. 2.—Two klinostats (*a* and *b*), the worm gear (*c*), and the electric motor back of the worm gear.

The worm gear (*fig. 3, a*).—As made by MILLER this reducing gear is manufactured in two sizes. In the smaller size the pulley worked by the worm has 100 teeth, thus reducing the speed to 0.01; in the larger size the pulley has 200 teeth, thus reducing to 0.005. Besides this reduction caused by the worm, the pulley attached to the worm shaft and receiving the belt from the motor is four times the diameter of the pulley of the motor shaft. Thus the total reduction by the worm gear brings the 1,600 revolutions of the motor down to four times or two times per minute, according to the use of the pulley with the 100 teeth or 200 teeth. A revolution of four times per minute has been shown by CZAPEK[4] to bring in centrifugal action unless the plant is kept within 5^{cm} of the axis of revolution; and hence, for merely neutralizing the effect of gravitation, one should still further

[4] CZAPEK, Untersuchungen über Geotropismus. Jahrb. Wiss. Bot. **27**:243. 1895.

reduce the speed from the smaller worm gear by interposing one of the step pulleys between the worm gear and the first klinostat. By the interposition of one such pulley, the speed of the first klinostat can be reduced to one revolution per minute, which is slow enough for objects less than one meter from the center of revolution. If desired, speed may be still farther reduced by other pulleys between the worm gear and the klinostat.

The shafts (*fig. 3, d*).—The shafts are of half-inch cold rolled steel, and are cut to any length.

The shaft supports (*fig. 3, c*).—These supports have a total minimum height of 12.5^{cm}, and by raising the upper part of the support may be extended to a height of 15.5^{cm}. This adjustment of the height of the support allows the shaft to be leveled up when the table or other object to which the supports are fastened is not level. The lower part of the support is a socket in which the stem of the upper part is held by a set-screw. The brass collar at the upper end of the support acts as a bearing, as shown in *fig. 1*, and automatically tilts up and down to conform to the direction of the shaft which passes through it. The middle piece of the support (*fig. 3, c*) has the shape of a tuning-fork, the stem of which is held in the socket below, and between the forks of which is received a plate projecting from the lower side of the collar above. An iron pin passing through the arms of the fork and the plate of the collar suspends and hinges the collar, and thus allows the automatic tilting. The three movements allowed the upper part of the support—that of vertical movement in the socket, rotation in the socket, and tilting of the collar—give ready adjustment to all possible faults of mounting of the shafts, prevent all binding, and have much to do with the easy running of the machines.

The pulleys (*fig. 3, d*).—The pulleys for the horizontal shafts are of cast iron, and made with three steps of 4, 8.5, and 15^{cm} diameter respectively. Each step has a peripheral thickness of 1^{cm} and has turned in it a V-shaped groove to take a quarter-inch leather belt. The pulleys are fastened to the shafts by set-screws.

Special turn-tables (*fig. 2, a* and *b*; *fig. 3, b*).—The foregoing apparatus is sufficient for centrifuges and klinostats revolving with horizontal axis. For revolution about a vertical axis the machines shown in the figures referred to have been made. They have an iron base $20 \times 14 \times 2.5^{cm}$. An iron support screwed to this base rises vertically and carries at its upper end a horizontal arm which holds a collar through which passes the half-inch shaft of the machine. One end of this shaft, as shown in the figures, receives a brass two-step pulley, and the other end the usual plate for supporting the object under experiment. This plate is of heavy brass 15–20^{cm} in diameter, and has cut in it three equidistant radial slots which receive the ends of brass posts. The brass posts have shoulders which rest upon the brass plate on the upper side (*fig. 2, a*), while nuts on the opposite side secure the posts at any desired distance from

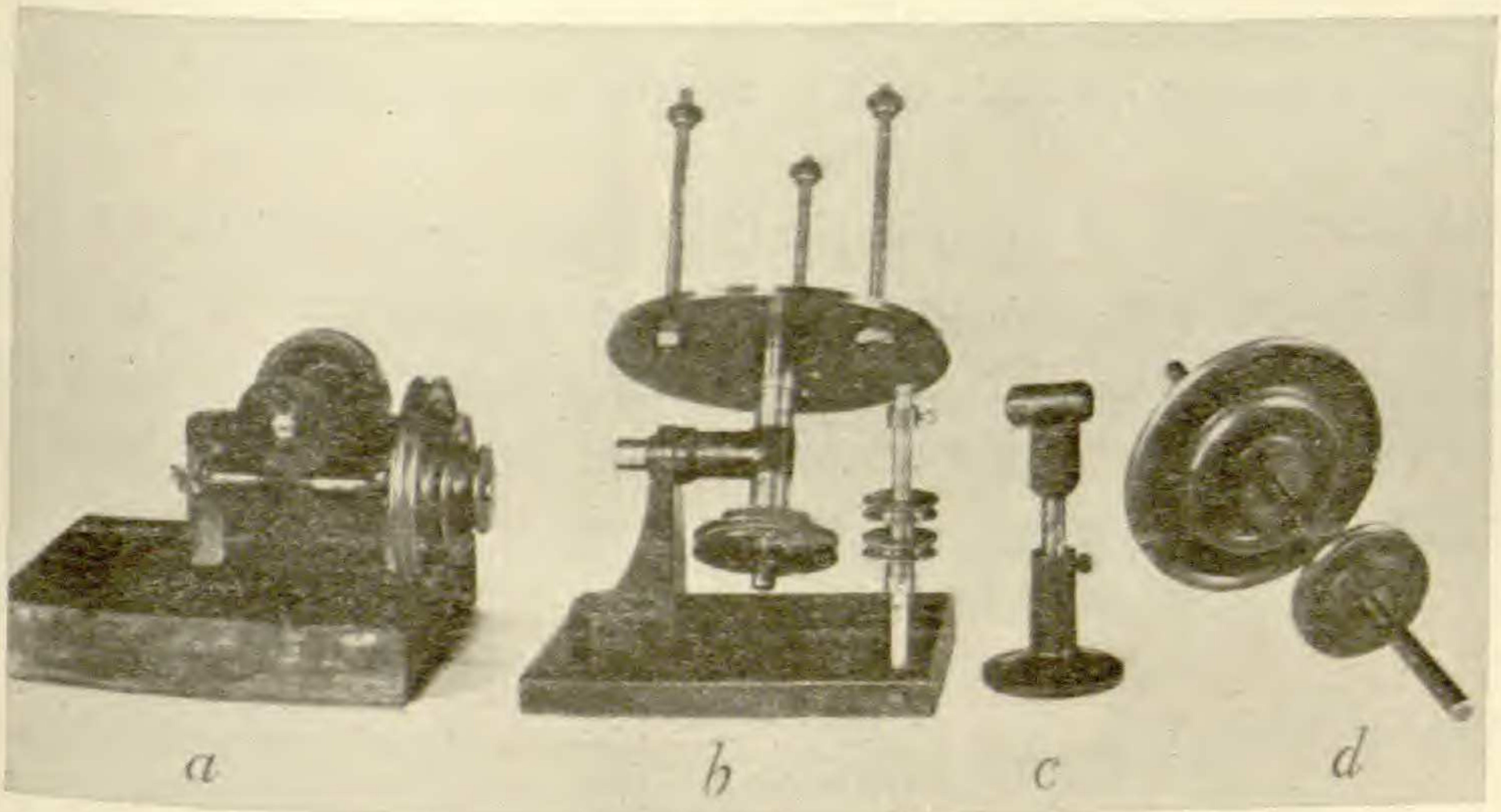

FIG. 3.—Worm gear (*a*), turn-table (*b*), shaft standard (*c*), and shaft and pulleys (*d*).

the center. The free ends of the posts have a thread on which runs a nut to be screwed down over the edge of a flower-pot or other container.

The horizontal arm projecting from the support rising from the base is held against the vertical support by a heavy friction screw passing through the vertical support and into the horizontal arm. This friction screw is turned by a removable steel rod passing through the head of the screw. By manipulating the friction screw, this machine may be set with its shaft at any angle desired, allowing the same klinostat to be used for revolution about a vertical, horizontal, or oblique axis (*fig. 2, a* and *b*).

Idler pulleys and support.—For adjusting the klinostats to cramped positions, or to fixed directions of light, it is often desired to turn a driving-belt from a straight course. This has been accomplished by means of the shaft and two small pulleys shown standing in the right-hand end of the klinostat base in *fig.* 3, *b*. This position of these idlers is right for the klinostat to which they are shown attached when the klinostat is adjusted for revolution with horizontal axis. For other purposes I have had made a cheap iron base into which the pulley shaft is set, and this device allows a belt to be turned at right or oblique angles anywhere desired.

Belting and couplings.—The belts used are of one-fourth inch leather. The thimble-like couplings screw over the ends of the belt and hook into one another. Both belting and couplings are common articles of trade.

Shaft-stops.—It is often desirable to keep a shaft from working out of some position in which it is placed or to prevent it being accidentally pushed out of position and thus destroying the alignment of the pulleys. For this purpose several collars are cut from half-inch brass tubing, and each collar is provided with a set-screw. Two such collars are shown one above and one below the small pulleys on the vertical shaft rising from the base of the klinostat (*fig. 3, b*).

Besides what has been already mentioned there are several things which might be added in commendation of this apparatus. It is easily portable, in spite of its seeming size. The parts may all be screwed to a movable table, or each part may be screwed to a piece of plank and the parts then clamped to tables. The shaft supports and bearings are easily shifted, placed nearer together or farther apart, so that one may use many shafts of various lengths with any two supports. One end of a horizontal shaft may be made to project any desired distance beyond a support, and the free end of the shaft may support a klinostat or centrifuge plate, thus allowing the plants used to be pushed into the recess of a window or into a small, closed chamber. The pulleys can be shifted to any position on the shafts, or any number of pulleys attached to a single shaft, thus allowing the turn-table driven by that shaft a variety of positions, or allowing several turn-tables to be driven from one shaft. The speed of revolution can anywhere be increased or diminished, and a variety of speeds can be otained from the same shaft at the same time by belting to larger or smaller steps on the pulleys.

A machine, however simple and however powerful, is of little use unless it will accomplish the purpose of its design. A klinostat, as is well known, must move through any quadrant in the same time it traverses its counter-quadrant. The experience of years has demonstrated that the apparatus here described is not faulty in this particular. Of course, the loads must be balanced, and this is done as on any klinostat. There is no danger from the creeping or stretching of the belts. The unevenness of motion imparted by a water-motor attached to a central system seems to have no effect in causing either heliotropic or geotropic curves on the klinostats, the irregularities of one minute apparently correcting those of another, since the irregularities are not periodic.

Cost.—The minimum cost for a complete unit of this apparatus may be given thus:

1 ¼HP electric motor with rheostat		$35.00
1 ¼HP water motor	$24.00	
1 worm gear	12.50	12.50
2 shaft supports	2.50	2.50
2 ft. ½ in. steel shaft	.12	.12
1 3-step pulley	1.50	1.50
1 klinostat (*fig.* 2, *a* and *b*) revolving on either vertical or horizontal shaft	9.00	9.00
Total cost	$49.62	or $60.62

The equipment contained in this list provides a centrifuge with horizontal axis, revolving 800, 400, 200, 100 times per minute, and almost any lower speed, and with a klinostat revolving on either a vertical or horizontal axis with speeds from the centrifuge rate down to one revolution in four minutes. Moreover, it allows one centrifuge and one klinostat to be operated at the same time, or two centrifuges to be operated at the same time.

Additional centrifuges or klinostats with horizontal axis can be obtained tor $6 each, and with vertical axis for $9 each.

When one considers that the standard spring klinostats with but one turn-table cost $60 to $80, it can be seen that for the same expenditure the apparatus described in this paper possesses many times the efficiency of those, not counting cost of power.

Should anyone desire to construct this apparatus, I shall be willing to give additional details; or I will gratuitously supervise the construction should any one wish to have the work done by Mr. Miller. In the latter case, application for construction should be made to Messrs. Eberbach & Son, Ann Arbor, Mich., into whose employ Mr. Miller has entered.

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